UTAH GEOLOGICAL AND MINERAL SURVEY

REPORT OF INVESTIGATION

NO. 212

ENGINEERING GEOLOGY FOR LAND-USE PLANNING FOR A PARCEL OF STATE-OWNED LAND EAST OF WASHINGTON, WASHINGTON COUNTY, UTAH

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July 1986

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prepared by
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INTRODUCTION

Background and Purpose

In response to a request from Kevin Carter of the Division of State Lands and Forestry (DSLF), the Utah Geological and Mineral Survey (UGMS) investigated State land in parts of secs. 12 and 13, T. 42 S., R. 15 W., and parts of secs. 7 and 8, T. 42 S., R. 14 W., Salt Lake Baseline and Meridian (fig. 1). The purpose of the investigation was to inventory geologic conditions on the property, including geologic hazards, and present that information in a format that would allow the DSLF to make informed decisions regarding future development of the parcel. In addition to providing data on general geology and hydrology, this report includes information on flooding, slope stability, foundation conditions, seismicity, and suitability for individual wastewater disposal systems. This report and included maps are to be used to identify areas affected by geologic hazards that would require further site-specific investigation once development begins. A glossary of terms is included in appendix 1.

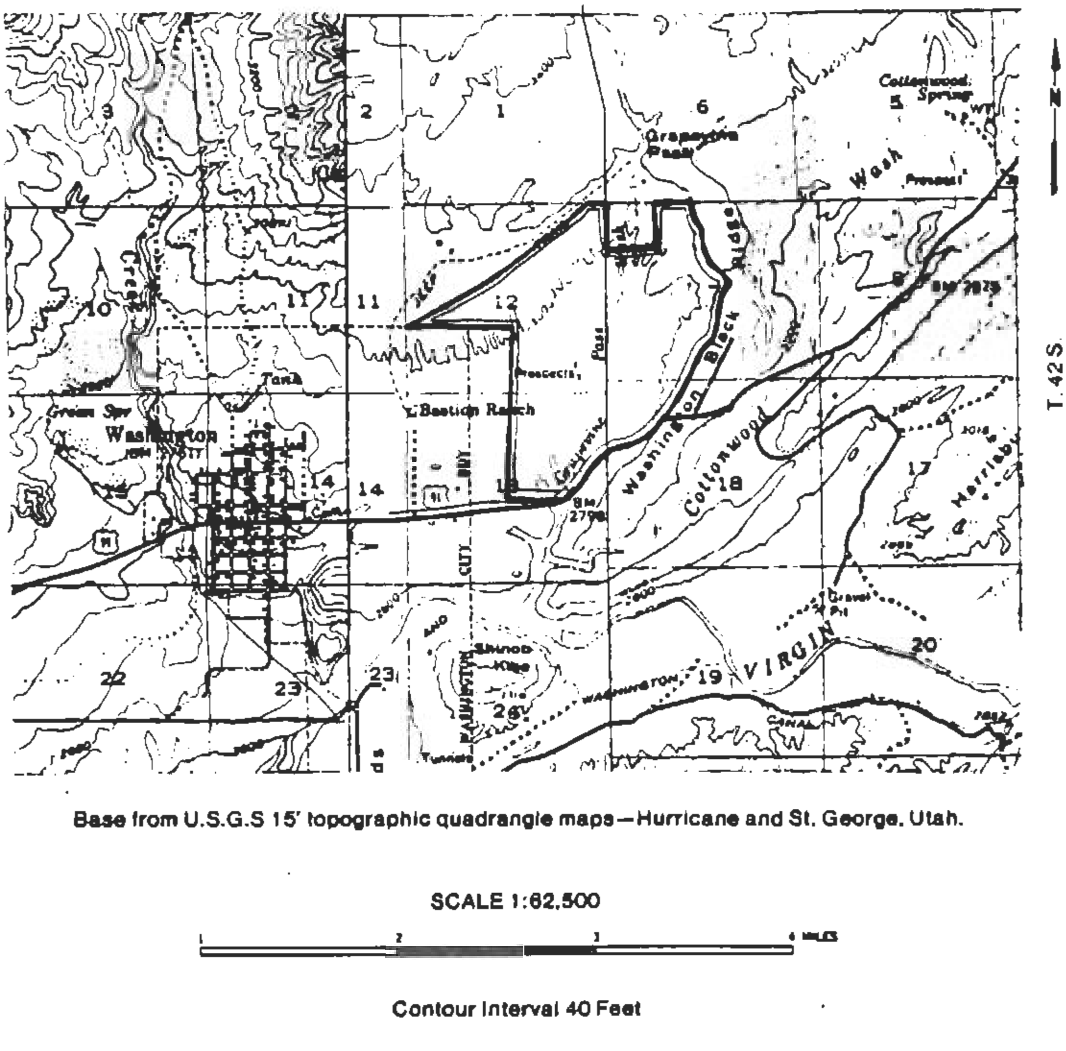
Scope of Work

The scope of work for this investigation included:

1. Review of published and available unpublished literature and other information including reports, maps, and well logs pertinent to the geology, hydrology, and soils of the site.

2. Examination of stereoscopic aerial photographs of the site taken in 1981.
3. A two-day field reconnaissance to verify existing data and to obtain additional information.
4. Report writing.

The scope of work did not include test borings, excavation of test pits, or laboratory testing.



Base from U.S.G.S 15' topographic quadrangle maps—Hurricane and St. George, Utah.

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Contour Interval 40 Feet

Figure 1. General location map of the site in Washingon County, Utah.

Setting

The site is less than one-half mile east of Washington, Utah and is bordered to the north and south by Interstate 15 and Highway 91, respectively (fig. 2). The crest of Washington Black Ridge forms the eastern site boundary, whereas the western border extends through badlands topography approximately 1100 feet east of Washington City. Grapevine Pass Wash, an intermittant, deeply incised drainage, crosses the site from north to south, dividing the parcel nearly in half. A number of ephemeral tributaries to the wash also cross the site. Elevations range from 3200 feet at the crest of Washington Black Ridge to slightly less than 2800 feet where Grapevine Pass Wash exits the site beneath Highway 91. Mean annual precipitation for the site is approximately 12 inches (Jeppson and others, 1968). Extending onto the site from the north is a small dam that ponds flow from Grapevine Pass Wash and an unnamed tributary (fig. 2). The dam is approximately 20 feet high and 700 feet across with no spillway. It appears to have been constructed with on-site material.

GENERAL GEOLOGY

The site lies in the St. George Basin of the Colorado Plateau physiographic province (Stokes, 1977). The St. George Basin is characterized by cuestas, buttes, and benches that formed when streams cut into gently dipping and folded rocks along the western edge of the Colorado Plateau (Christenson and Deen, 1983). Washington Black Ridge is a former tributary channel to the Virgin River along which lava flowed during Quaternary time (Hamblin, 1963). The lava armored the channel bottom, and erosion of the surrounding softer sedimentary rocks has resulted in an inversion of topography with the old stream channel now a resistant basalt ridge.

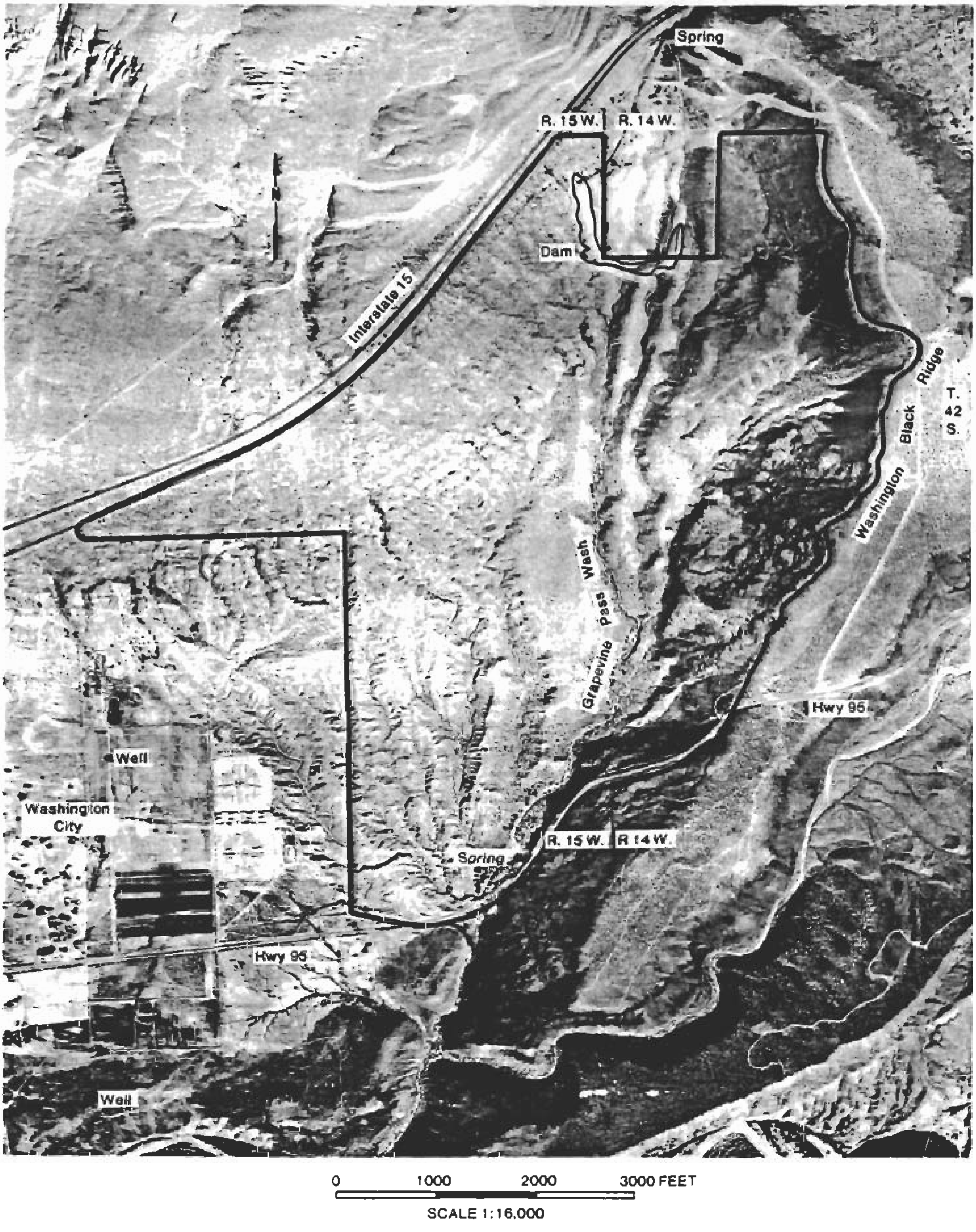


Figure 2. Site map.

Grapevine Pass Wash appears to be the remnant of a former alluvial channel that eroded softer bedrock west of Washington Black Ridge. Presently it appears to contain flow only in response to cloudburst storms.

Stratigraphy

Geologic units exposed at the site include Triassic-age bedrock and Quaternary-age unconsolidated deposits (fig. 3 and appendix 2). Bedrock includes the Triassic Moenave and Kayenta Formations. The Triassic Petrified Forest Member of the Chinle Formation does not crop out on the site, but it is present at shallow depth beneath a thin layer of colluvium (Qms on fig. 3) and therefore is described in this report. Outcrops of the Dinosaur Canyon Sandstone Member of the Moenave Formation are present in the nearly vertical banks of drainages at isolated locations, but are too small to depict on the geologic map.

The Petrified Forest Member of the Chinle Formation consists of variegated red-brown, purple, green, and blue shale with local sandstone, gypsum, and bentonite interbeds. Discomformably overlying this unit is the Dinosaur Canyon Sandstone Member of the Moenave Formation which consists of red to green, thin-bedded shale, siltstone, and sandstone (fig. 4). Overlying the Dinosaur Canyon Member is the Springdale Sandstone Member which is a ledge-forming white to red sandstone with thin shale lenses (Harshbarger, and others, 1957; Cook, 1960; figs. 3 and 5). This member of the Moenave Formation is conformably overlain by the Kayenta Formation (figs. 3 and 6). The Kayenta Formation consists of interbedded red sandstone, siltstone, and shale.

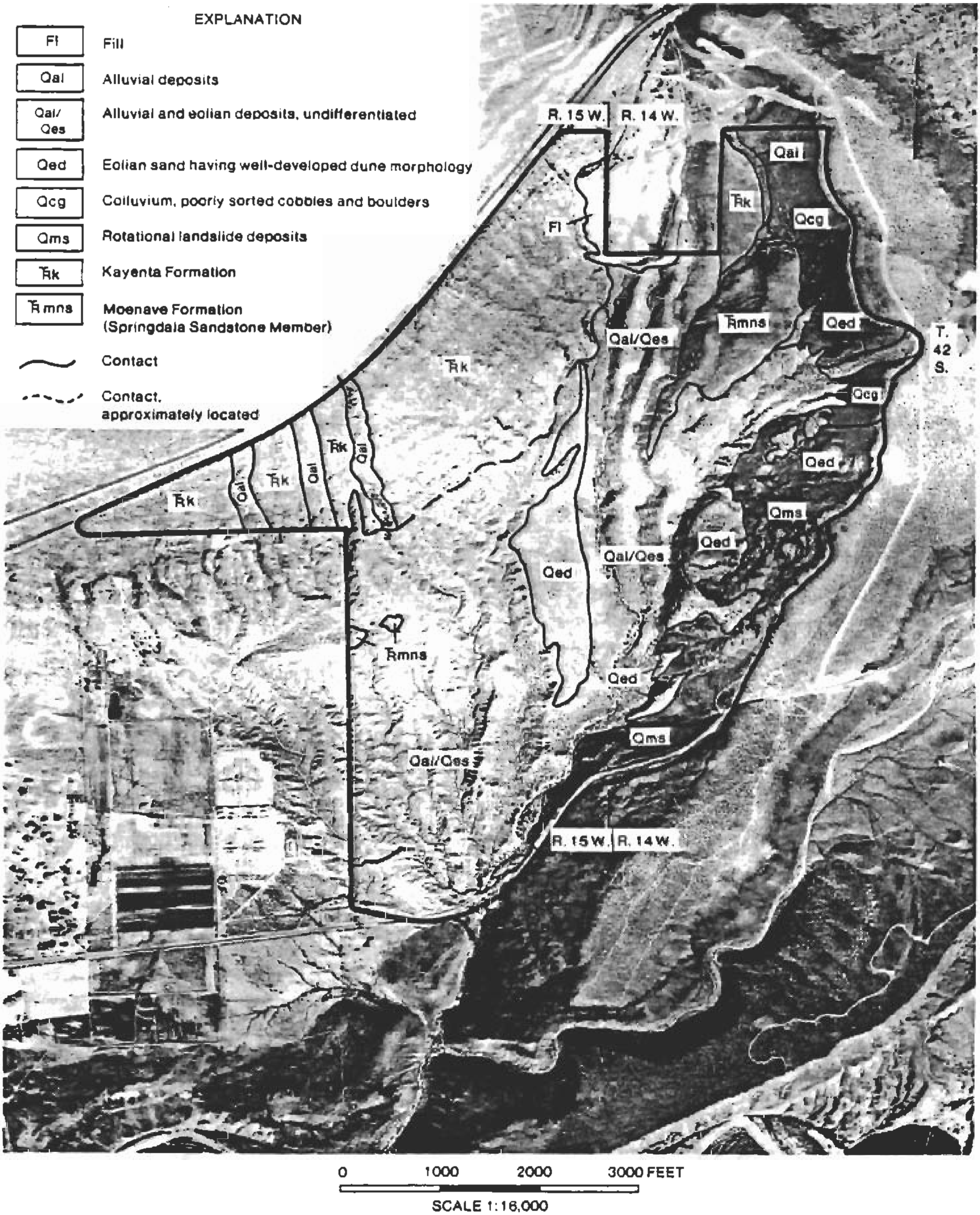


Figure 3. Geologic map.

Figure 4. Dinosaur Canyon Sandstone Member of the Moenave Formation. Field book is used for scale.

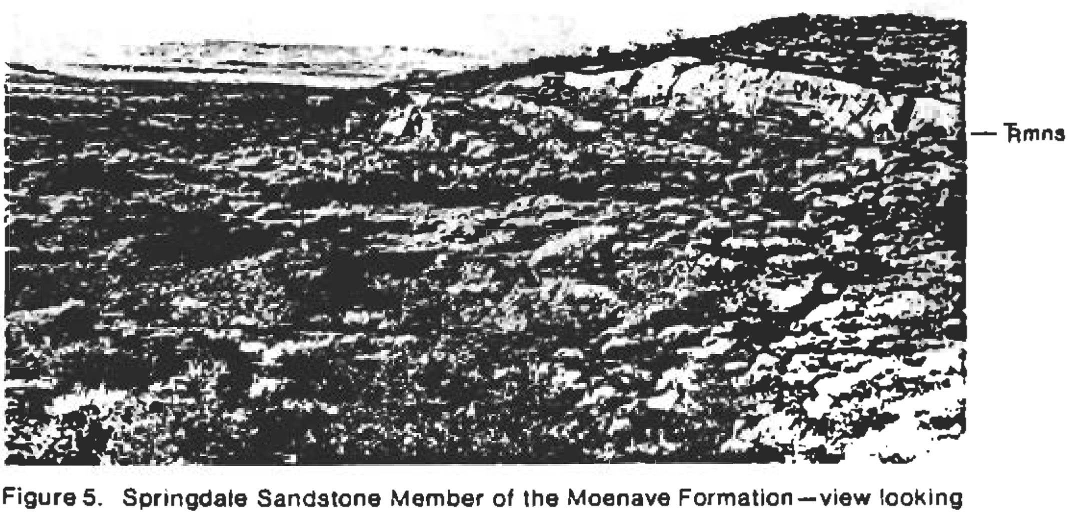
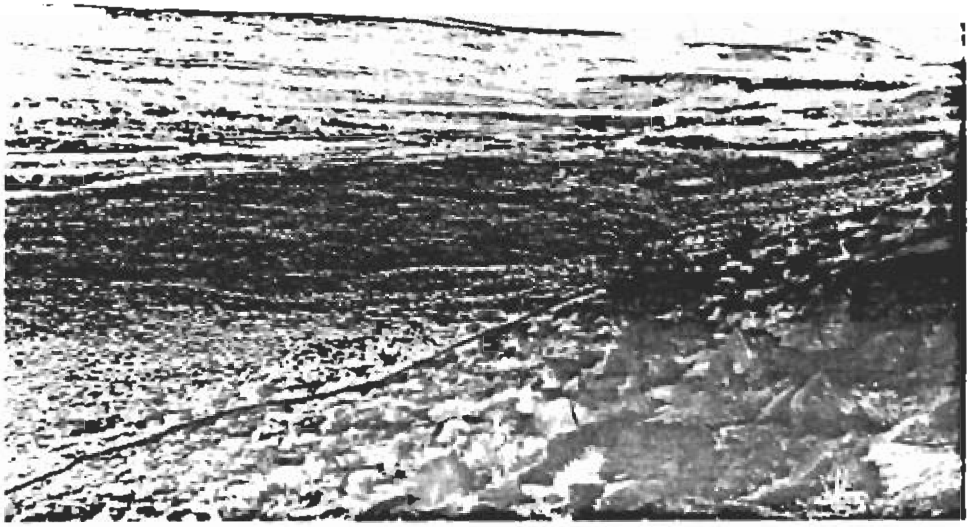


Figure 5. Springdale Sandstone Member of the Moenave Formation—view looking west.

Quaternary unconsolidated deposits cover more than two-thirds of the site (fig. 3). These deposits consist of alluvial gravel, sand, silt, and clay that have been locally reworked by wind. The steep slopes on the western flank of Washington Black Ridge are covered by colluvium consisting of cobbles and boulders representing rockfall debris from the basalt cap (fig. 7). The colluvium forms a veneer less than 4 feet thick covering the Kayenta and Moenave Formations (Qcg on fig. 3). Immediately to the south, rotational slumping has occurred where the colluvial slopes are underlain by the Petrified Forest Member of the Chinle Formation (Qms on fig. 3 and fig. 8). According to Christenson and Deen (1983) failure is not occurring today, but was active during late Pleistocene and possibly early Holocene time. No evidence of recent slumping was observed during the field investigation for this study.

Figure 6. Kayenta Formation—view looking north.



— Qcg

Figure 7. Basalt colluvium covering west flank of Washington for Black Ridge—view looking north.

Qms —

Figure 8. Hummocky topography resulting from rotational failures in the Petrified Forest Member of the Chinle Formation overlain by colluvium—view looking southwest.

Structure

The St. George Basin is a major fault block within the structural system that forms the western border of the Colorado Plateau (Hamblin, 1970). The basin has been downthrown along the Hurricane Fault located 10 miles east of the site (fig. 9). Total displacement across the fault is 6000 to 8000 feet with major movement occurring after Miocene time (Anderson and Mehnert, 1979). Movement of this fault is evident at several locations where Pleistocene basalts and alluvial fans have been displaced (Earth Sciences Associates, Inc., 1982). Two other major north-striking normal faults are found in the Washington area (fig. 9). The Grand Wash Fault, located 15 miles west of the site, is suspected to have been, but not proven to be, active in Quaternary time (Anderson and Miller, 1979). This fault forms the west edge of the St. George Basin. The Washington Fault, less than two-thirds mile west of the site, is the more prominant of these two faults. Earth Sciences Associates, Inc. (1982) dated Holocene movement on this fault. No known faults are located on the site.

The major structural feature in the St. George Basin is the Virgin anticline, the axis of which trends in a northeast direction less than one-half mile southeast of the site (Cook, 1960). The northwest flank of this anticline passes beneath the site at dips ranging from 9 to 23 degrees to the northwest.

GROUND WATER

The site is located in the Central Virgin River Basin where both unconsolidated sediments and rocks yield water to springs and wells.

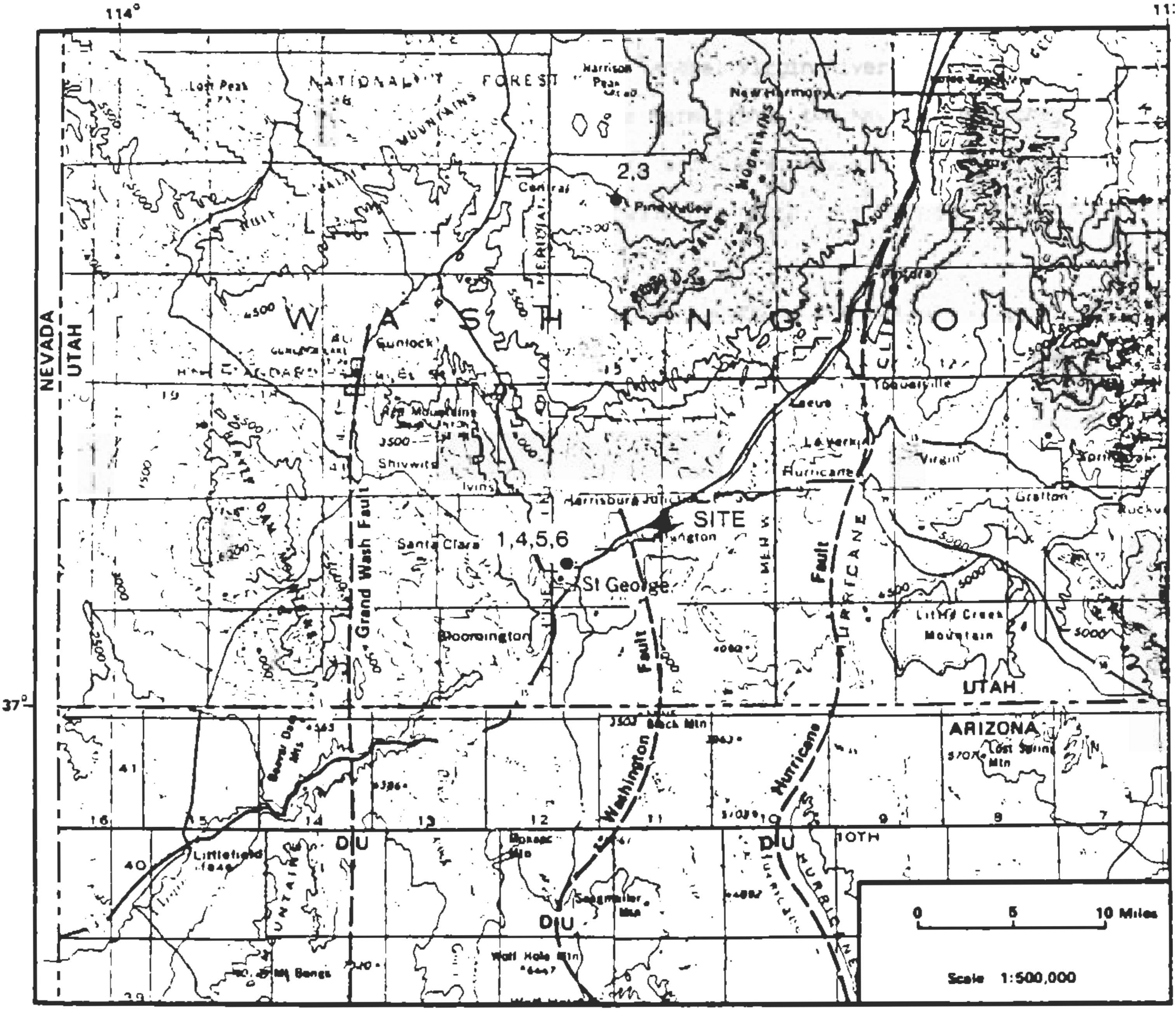


Figure 9. Approximate locations of main traces of major faults (D, downthrown side; U, upthrown side) and earthquake epicenters Magnitude 4.0 or greater listed in Table 1 (1850 to March, 1986). (Modified from Christenson and Deen, 1983.) Note: Epicenters 1, 4, and 5 in the St. George area are approximately located based on accounts of felt earthquakes.

Unconsolidated deposits cover 20 percent of the basin but yield about 80 percent of the water discharged by wells; the water comes primarily from unconsolicated basin-fill deposits in low-land areas (Cordova and others, 1972). Thin, channel-fill deposits of small areal extent discharge water to springs and wells that supply small amounts of water.

The principal bedrock aquifers in the Central Virgin River Basin are in the Moenkopi, Chinle, Moenave, and Kayenta Formations, the Navajo Sandstone, igneous rocks in the Pine Valley Mountains, and Quaternary basalts (Cordova and others, 1972). Most springs in the basin discharge from bedrock.

Based on the logs of water wells shown in figure 2, the shallow aquifer beneath the site appears to be in bedrock more than 100 feet below the ground surface with flow to the south. At the time of the investigation a small spring was found in the southern part of the site. It was discharging from colluvium (Qms) overlying the Chinle Formation that forms the southern bank of Grapevine Pass Wash at this location (fig. 2). Figure 10 shows a large number of springs discharging from what appears to be the Kayenta Formation west of the site (Cordova and others, 1972). One of the springs is located on the site. However, no evidence of this spring was found during this investigation indicating it may flow only during late spring or early summer or in response to cloudburst storms. A second spring, found during the investigation, is located approximately 1500 feet north of the site and appears to be discharing from the Kayenta Formation.

SOILS

Both residual and transported soils are present on site. Soil classifications and grain-size classes used in this report conform to the Unified Soil Classification System (USCS, appendix 3). Residual soils develop on bedrock and consist of weathered, disintegrated rock that has not been transported by wind or water. More resistant rock types such as the Kayenta Formation and the Springdale Sandstone Member of the Moenave Formation have essentially no soil cover. Residual soils are localized and erratic in occurrence, and may be several inches to several feet thick in areas otherwise mapped as bedrock (fig. 3). The composition of these soils is primarily clay, silt, and sand. The soil character depends largely on parent rock type; sandstone yields sandy soils (SP), whereas shale, mudstone, and siltstone produce silty and clayey soils (CL, ML, CH, MH).

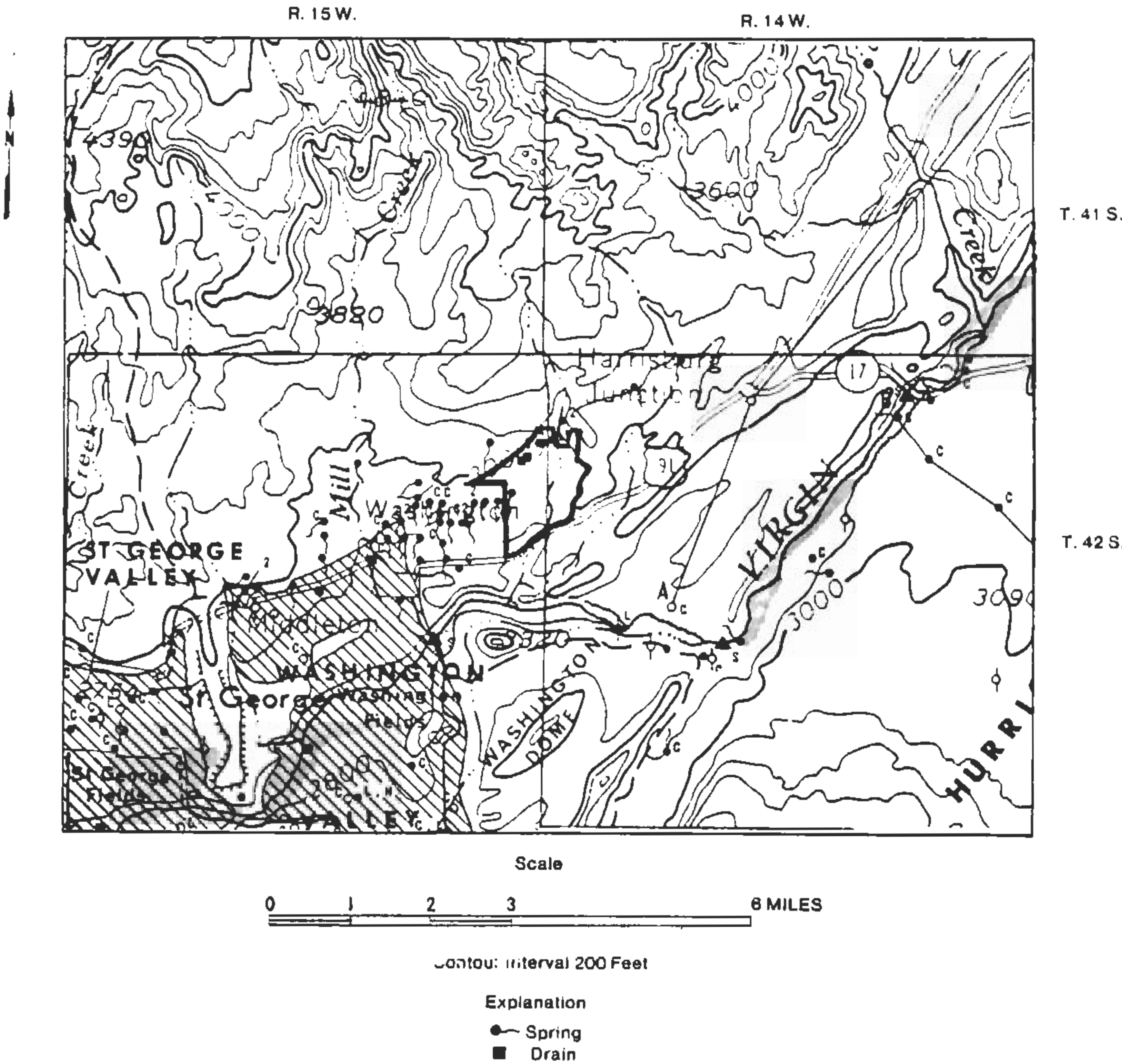


Figure 10. Map showing large number of springs west of the site (modified from Cordova and others, 1972).

Figure 11. Alluvial clay, silt, sand, and gravel in bank of Grapevine Pass Wash.

Figure 12. Debris flood deposits in channel of Grapevine Pass Wash.

Transported soils include: 1) alluvium, 2) eolian deposits, 3) colluvium, and 4) fill. Alluvium (fig. 3) is principally sand (SP), but includes silty and clayey sand (SM, SC, SM-SC), gravel (GP), and silty and clayey gravel (GM, GC, GM-GC) (fig. 11). Flood-deposited boulders, as much as 4 feet in diameter, are found in the channel of Grapevine Pass Wash (fig. 12). Eolian deposits consist of alluvial sand reworked by the wind, forming dunes at some locations (fig. 13). The USCS symbol for these deposits is SP. In many areas it is difficult to differentiate between the eolian and alluvial deposits. Where this occurs a dual symbol is used on figure 3 (Qal/Qes). Colluvial deposits consist of cobbles and boulders forming a layer of variable thickness on slopes up to 30 percent (figs. 7 and 8). Immediately adjacent to the site on the north is an area reworked to construct the small dam (figs. 2 and 14). Part of the embankment is on site and is shown on figure 3 as Fl. The dam appears to have been constructed from alluvial/eolian deposits similar to those described on the site.

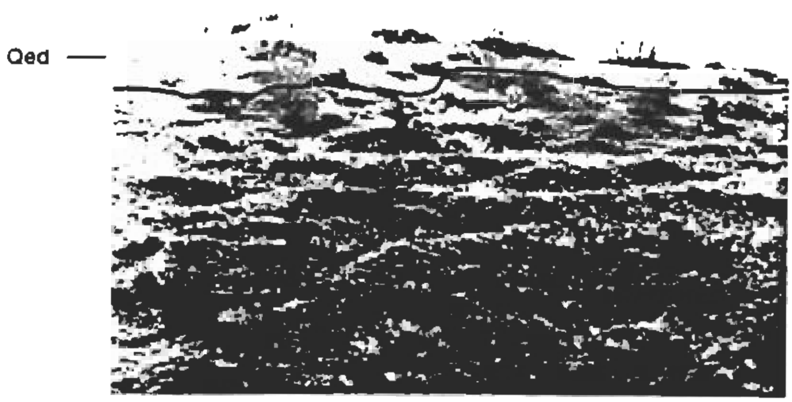


Figure 13. Eolian sand dunes overlying alluvium.

Figure 14. Dam and graded area.

GEOLOGIC HAZARDS

Geologic hazards considered in this study include flooding, slope failure, erosion, adverse foundation conditions, seismicity, and soil conditions with regard to suitability for individual wastewater disposal systems. These hazards can affect development on the parcel and must be taken into account in planning.

Flooding

Flooding in the St. George-Washington area is chiefly in response to cloudburst storms during the summer months (Christenson and Deen, 1983). A number of ephemeral tributaries to Grapevine Pass Wash could experience significant flow from such storms for short periods of time (fig. 15).

Debris, similar to that shown in figure 11, is evidence of significant flooding in these tributaries. The flood hazard in Grapevine Pass Wash has been reduced by the construction of the previously described dam (fig. 14). However, the dam does not appear to be constructed to standards that will contain a 100-year flood. No water was in the dam at the time of the site investigation. In addition to possible channel flooding the site could experience sheet wash in areas where bedrock is at or very near the surface. The areas considered most susceptible are delineated in figure 15.

Slope Failures

The stability of natural bedrock slopes is dependent on lithology, ground-water conditions, and the attitude of bedding or jointing (Christenson and Deen, 1983). Types of failures most likely to affect bedrock slopes are falls, topples, and slides.

Rockfalls are downslope movements of rock masses or single blocks by freefall, rolling, bouncing, or toppling mechanisms (Varnes, 1978). The basalt cap on Washington Black Ridge is susceptible to this type of failure, and debris from that source has resulted in the colluvial-covered slopes shown in figure 3. Rockfall is occurring on the site.

Rotational failures or rock slumps occur when a weak layer fails and a block of material moves downslope along a bowl-shaped, concave-upward slide plane (Varnes, 1978). The Petrified Forest Member of the Chinle Formation underlying the colluvial slope Qms on the west flank of Washington Black Ridge (fig. 3) has failed in this manner. The slope is characterized by a series of slumps resulting in stepped topography (fig. 8). Most landslide activity

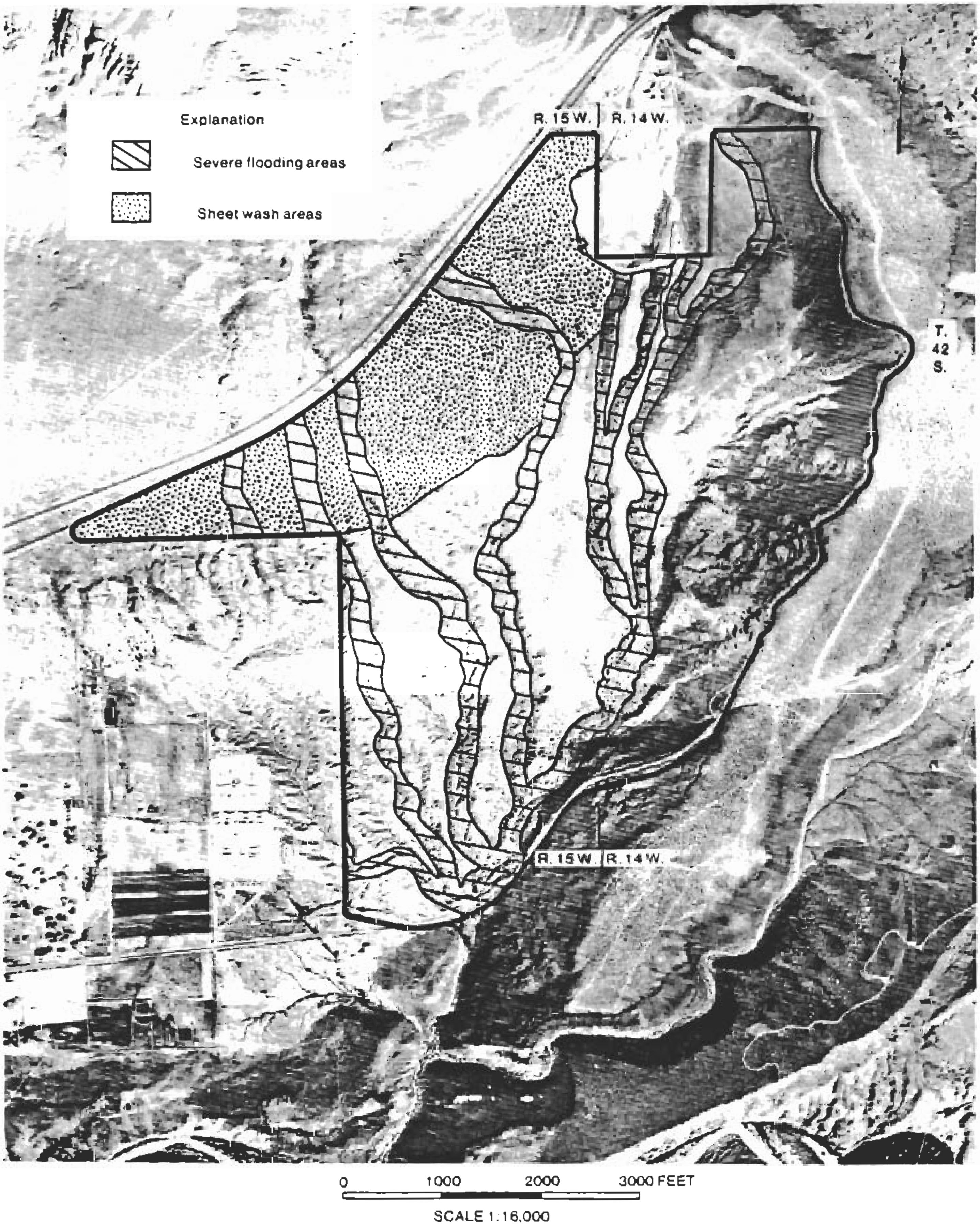


Figure 15. Areas of potential channel flooding and sheet wash.

occurred during wet intervals in Pleistocene time (Christenson and Deen, 1983). No evidence of recent slumping was observed during the investigation, although removal of material at the base of the slope or the addition of load (structures) and irrigation could renew failure activity. Other bedrock units on the site showed no evidence of slope instability.

Slopes in unconsolidated deposits on the site, other than colluvial slopes previously discussed, appear stable under present conditions. Flooding in drainages on the site could undermine banks, making them locally unstable. The stability of unconsolidated materials in construction excavations is unknown and should be determined during foundation investigations for individual projects.

Erosion

Channel and, to a lesser degree, wind erosion are occurring on the site. Channel erosion results from concentrated flow in gullies and channels and is significant in the southwest part of the site (fig. 16). Numerous gullies have entrenched into the banks of drainages in this area. The headward migration of these gullies could eventually undermine the foundations of any structures built in this part of the site. Although fluvial erosion is more destructive, wind erosion is also active and could cause problems resulting from dune migration across developed areas. Active dune areas are shown on figure 3 (Qed).

Adverse Foundation Conditions

Conditions that may adversely affect foundations are: 1) expansive clays, 2) dissolution of gypsum, and 3) shallow ground water. Expansive clays cause

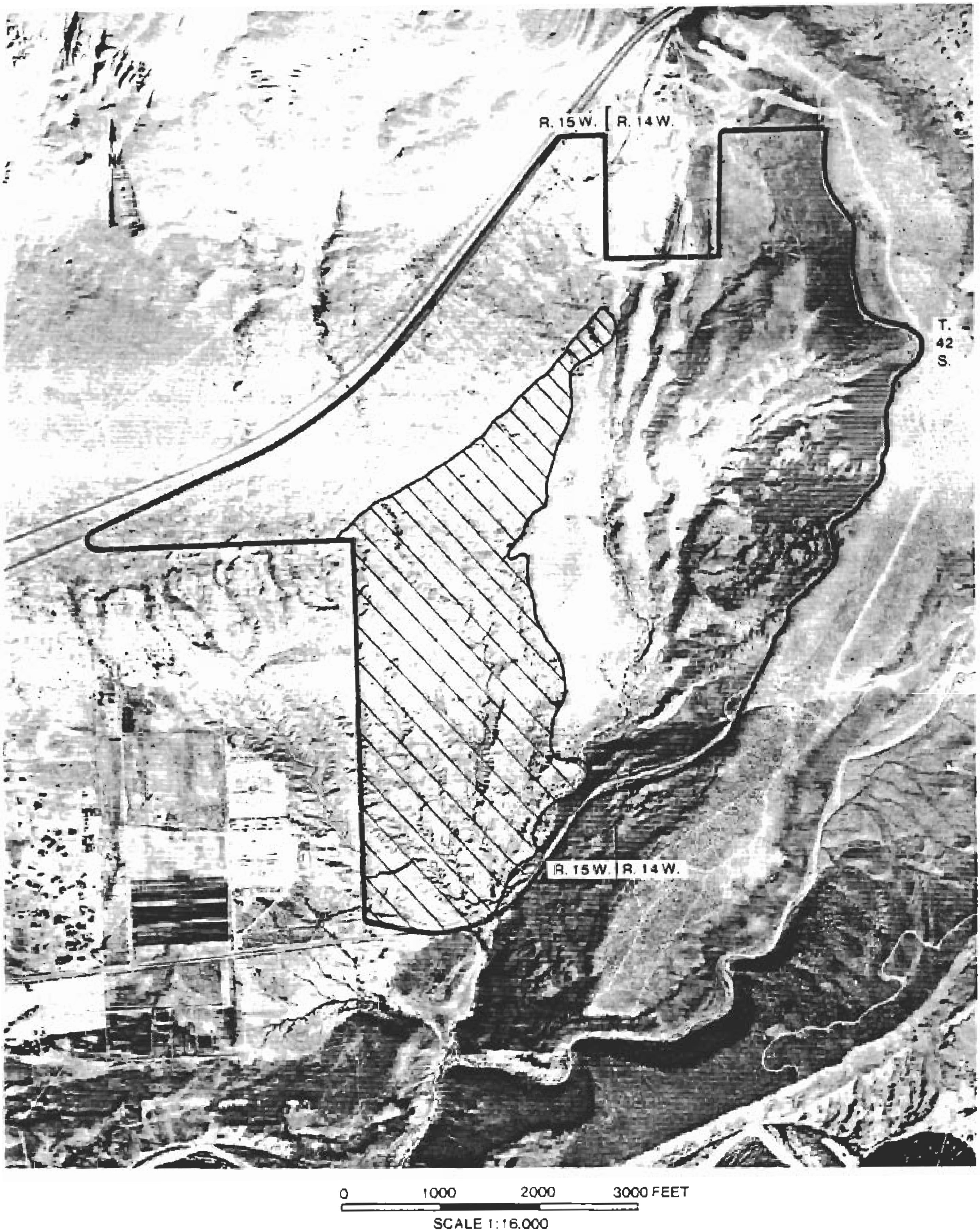


Figure 16. Area of severe erosion susceptibility.

differential settlement or heave with changes in moisture content and result in cracking and failure of foundations. Expansive clays are found in the Petrified Forest Member of the Chinle Formation. Although the Petrified Forest Member does not crop out in the study area, it is only covered by a thin layer of colluvium (fig. 3) and, therefore, could be exposed in foundations for structures built in those areas.

Gypsum is subject to dissolution by water (ground water and irrigation water) that can result in soil collapse. Gypsum can also have a deleterious affect on concrete. Gypsum is abundant in both the Petrified Forest Member of the Chinle Formation and the Dinosaur Canyon Sandstone Member of the Moenave Formation. The only outcrops of Dinosaur Canyon Sandstone on the site occur in isolated locations in the near-vertical lower banks of Grapevine Pass Wash (fig. 4). At these locations, the Dinosaur Canyon Sandstone is covered by significant thicknesses of alluvium and eolian deposits and foundations would probably not extend to that depth. However, the Dinosaur Canyon Sandstone may be exposed at some other locations where overlying sediments are thinner. Mortensen and others (1977) described the lower section of the Kayenta Formation as actively eroding shale with interbedded layers of gypsum. No other literature reviewed for this report associates gypsum with the Kayenta Formation and no gypsum layers in this unit were observed in the field. Precaution should be taken, however, to test for the presence of gypsum at all foundation locations because of its solution characteristics.

Shallow ground water can cause expansion of clays, leaching of gypsum, and flooding of basements. The regional shallow ground-water table is more than 100 feet below the surface of the site and will not affect foundations. Therefore, only localized areas of perched ground water represent a problem.

The only evidence of perched ground water noted during the site investigation was the small spring previously discussed. This spring seeps from colluvium covering the Chinle Formation forming the southern bank of Grapevine Pass Wash. The high permeability of alluvium in the floor of the wash allows total infiltration of discharge within a few feet. The spring Cordova and others (1972) identified on site would appear to be recharged from ground water in the Kayenta Formation. This spring may no longer exist or may only flow during periods of high recharge or in response to cloudburst storms. The possibility of springs discharging intermittantly should be considered during planning for this part of the site. Areas where bedrock or low-permeability clays are at shallow depth could develop perched ground water recharged by irrigation. This perched water could flood basements or adversely affect foundations. Geotechnical investigations for individual projects should determine if these conditions exist in areas proposed for development.

Unweathered rock formations provide incompressible and therefore favorable foundations, but may present excavation difficulty. The Springdale Sandstone Member of the Moenave Formation appears to be the most resistant to excavation (fig. 3). Areas on the site where bedrock needs to be excavated may require blasting.

Seismicity

The site is located in the Intermountain Seismic Belt, a zone of high seismic activity extending from northern Arizona to northwestern Montana (Smith and Sbar, 1974). In Utah, this zone generally follows the north-south-trending Hurricane and Wasatch fault zones.

A tabulation of historical earthquakes of Richter magnitude 4.0 or greater within 20 miles of the site is presented in table 1. A plot of earthquake epicenters is presented in figure 9. No magnitude 4.0 or greater earthquakes have been recorded since 1949. The largest historic earthquake (magnitude 6.3) was 18 miles north of the site.

Two studies have calculated maximum expected earthquake magnitudes for southwestern Utah. Thenhaus and Wentworth (1982) calculated magnitudes of as much as 7.5 for the Hurricane fault and less than 7.5 for the Washington and Grand Wash faults (fig. 9). Earth Sciences Associates, Inc. (1982) determined the maximum credible earthquake that can be generated by either the Grand Wash or Washington faults to be 7.0. Based on historical seismicity and the geology of southwestern Utah, Earth Sciences Associates, Inc. (1982) indicate the recurrence interval for an earthquake of magnitude 7.0 to 7.5 on one of

TABLE 1

Index to Nos. in Fig. 9.	Date	Magnitude	Maximum Intensity	Epicenter Location	
				Latitude (N)	Longitude (W)
1	04/20/1891	5.0*	VI	37° 06.38′	113° 34.41′
2	11/17/1902	6.3*	VIII	37° 23.58′	113° 31.20′
3	12/05/1902	5.0*	VI	37° 23.68′	113° 31.20′
4	11/23/1903	4.3*	V	37° 06.38′	113° 34.41′
5	11/26/1920	4.3*	V-VI	37° 06.38′	113° 34.41′
6	11/02/1949	4.7	VI	37° 06.38′	113° 34.41′

Sources: Christenson and Deen (1985); University of Utah Seismograph Stations (1986).

*Magnitude not instrumentally measured, but estimated from maximum modified Mercalli intensity assuming Gutenberg-Richter relation (Gutenberg and Richter, 1956).

Table 1. Earthquakes of Richter magnitude 4.0 or greater in the site area, 1850 to March 1986.

these three faults to range from 1,000 to 10,000 years and 236 to 365 years for a magnitude 6.0 event. Prior to the study by Earth Sciences Associates, Inc. (1982), the youngest dated faults relative to the site were considered to be late-Pleistocene and located 5.5 miles to the east in the Hurricane fault zone (Anderson and Miller, 1979). Earth Sciences Associates, Inc. (1982), however, dated Holocene movement on the Washington fault 4.0 miles south of the site.

Earthquakes producing maximum Mercalli intensities of VIII or greater have occurred in southwestern Utah (appendix 4). Faults are not present on the site and, therefore, ground rupture is not expected. However, the study area could experience severe ground shaking from moderate to large earthquakes that could accelerate rockfall on Washington Black Ridge and damage or destroy stuctures not properly designed to withstand seismic forces. The Utah Seismic Safety Advisory Council (USSAC) and the Uniform Building Code (UBC) place the site in seismic zone 2 for which the maximum modified Mercalli intensity expected is VII. The UGMS accepts UBC seismic zone 2 as appropriate for most construction in the area and believes that the UBC seismic zones should not be changed without strong justification. However, for critical facilities (hospitals, public safety buildings, schools) construction conforming to UBC seismic zone 3 guidelines is recommended for added safety (Christenson, 1984).

Suitability for Soil Absorption Systems

Conditions suitable for wastewater disposal systems utilizing septic tank and soil absorption fields are dependent on soil type and permeability, slope, flood hazard, depth to ground water, depth to bedrock, and erosion susceptibility. Much of the site is poorly suited for absorption systems because of exposed or shallow bedrock, steep slopes, or flood and erosion hazard. Areas designated as Kayenta Formation, Moenave Formation, fill, and colluvium on figure 3 are unsuitable. The areas designated as alluvial/eolian and eolian may be suitable except where shallow bedrock, steep slopes, or flood hazard are present. Furthermore, areas with poorly graded sands and gravels or fines may also be unsuitable because of excessively high or excessively low permeability, respectively. The area on the site with the greatest potential for developing soil adsorption field systems is shown on figure 17. In other areas wastewater systems could conceivably be developed, however, by using alternatives to the standard septic tank and disposal field presently being evaluated by the Utah Department of Health.

CONCLUSIONS AND RECOMMENDATIONS

The parcel of land investigated for this study can be developed in a safe and efficient manner with proper planning based on a knowledge of natural conditions. The following major hazard conditions have been identified on the site and should be addressed during planning for future development.

1. Flooding with possible debris flooding in Grapevine Pass Wash and other intermittent drainages.

2. Erosion in some areas of the site.

3. Rockfall from basalt capping Washington Black Ridge and rotational slumping in the Chinle Formation.

4. Expansive clays in the Chinle Formation.

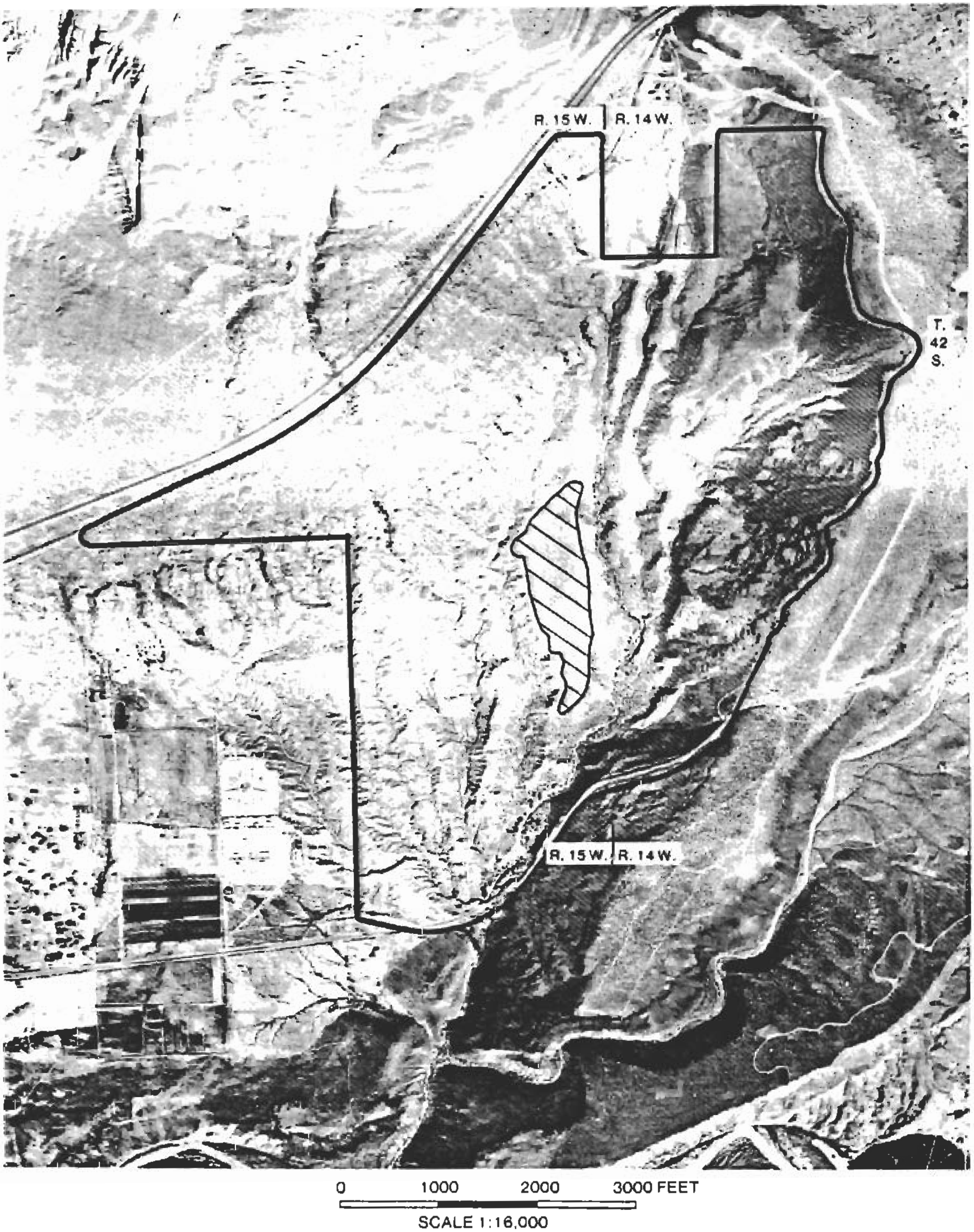


Figure 17. Area most suitable for wastewater disposal systems.

5. Gypsum in the Chinle, Moenave, and possibly Kayenta Formations.

6. Seismic ground shaking.

7. Unsuitability for soil absorption systems.

Based on these hazards, the following recommendations for general planning are made:

1. Development is not recommended in active stream channels (fig. 15) unless flood-control measures are implemented. Although less of a hazard, sheet wash should be controlled upslope from development on the Kayenta Formation.

2. Erosion is active on the site, being most severe in the southwest. If erosion and drainage control measures are implemented, most areas can be developed. Where control measures are not employed, adequate setback distances normal to gully and channel walls, and to gully heads should be determined prior to development in the area of severe erosion in the southwest part of the site. Flow in the ephemeral tributaries should be diverted or otherwise controlled.

3. The part of the flank of Washington Black Ridge underlain by the Chinle Formation is not recommended for development due to past landslide activity. The remainder of the flank is underlain by more competent bedrock and can be developed if rock-fall protection measures are implemented (berms, angle cuts, wire-mesh fences).

4. Foundation investigations should be performed for all proposed buildings and cut slopes. The possibility of expansive clays and gypsum in soil and bedrock should be carefully investigated. Critical facilities require an evaluation of ground response resulting from seismic shaking.

5. Construction should at least conform to UBC seismic zone 2 standards. For an additional factor of safety, critical facilities should conform to UBC seismic zone 3 guidelines.

6. Much of the site appears unsuitable for conventional soil absorption systems. However, alternative systems presently being evaluated by the Utah Department of Health may allow for development in many of these areas.

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Appendix 1

GLOSSARY OF TERMS

Alluvium: Sedimentary deposits resulting from deposition by streams.

Anticline: A fold in rock strata that is convex upward.

Aquifer: Stratum or zone below the surface of the earth capable of producing water as from a well.

Bench: A strip of relatively level earth or rock, raised and narrow.

Bentonite: Clay formed by the decomposition of volcanic ash, generally highly expansive.

Colluvium: Poorly sorted mixture of angular rock fragments and fine-grained materials moved by gravity.

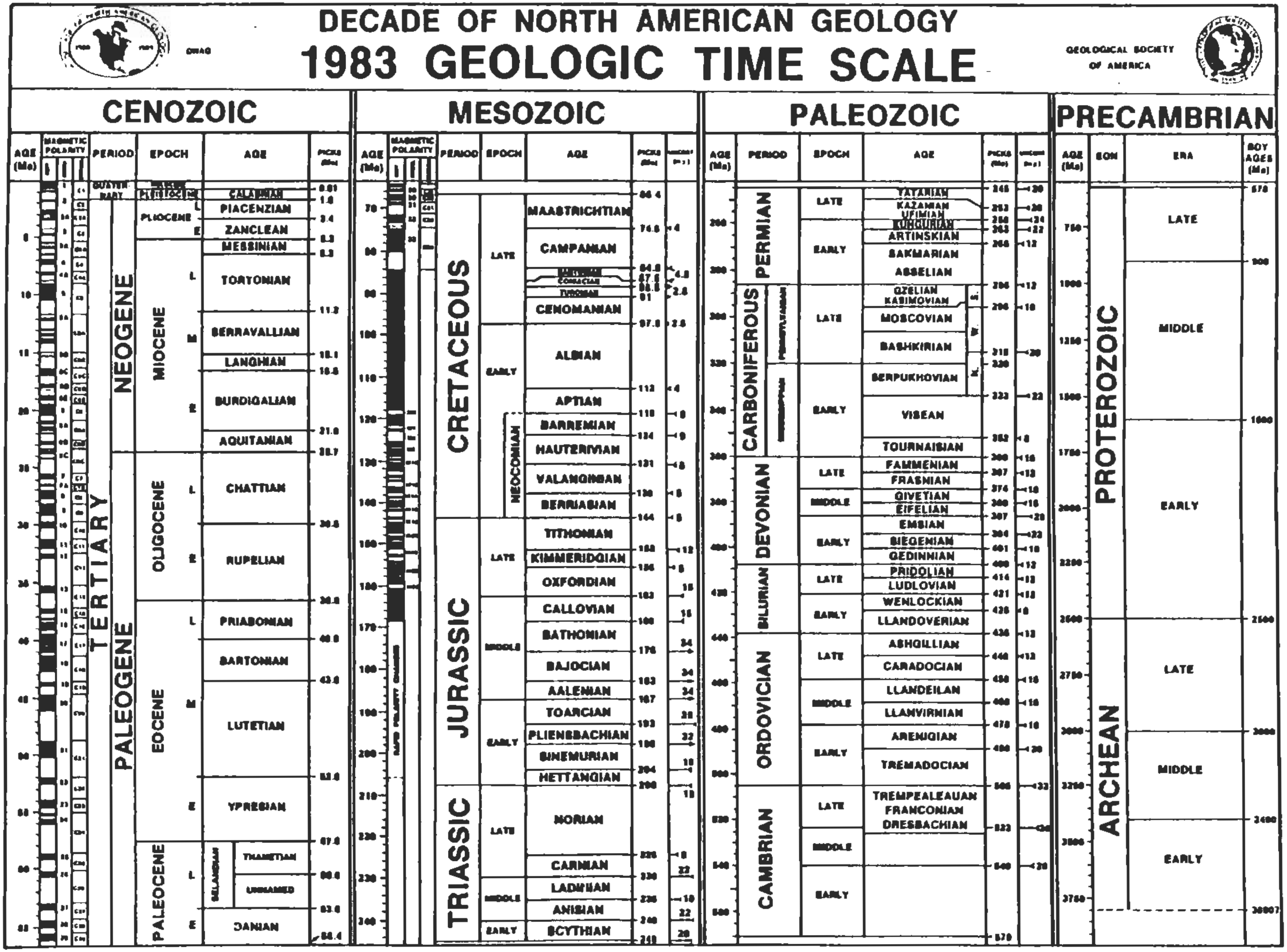
Cuesta: Sloping surface terminated on one side by a steep slope, formed on gently dipping resistant rock layers.

Eolian: Resulting from the action of wind.

Ephemeral drainage: Drainage that flows only in response to precipitation, otherwise dry.

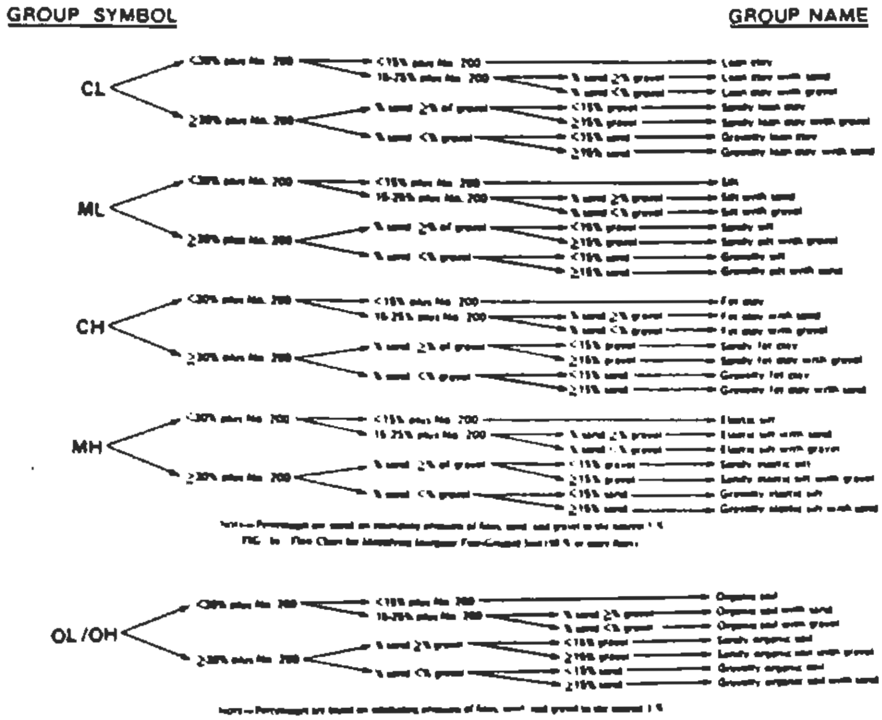
Normal fault: A fault where the hanging wall (upper block) has moved downward relative to the footwall (lower block).

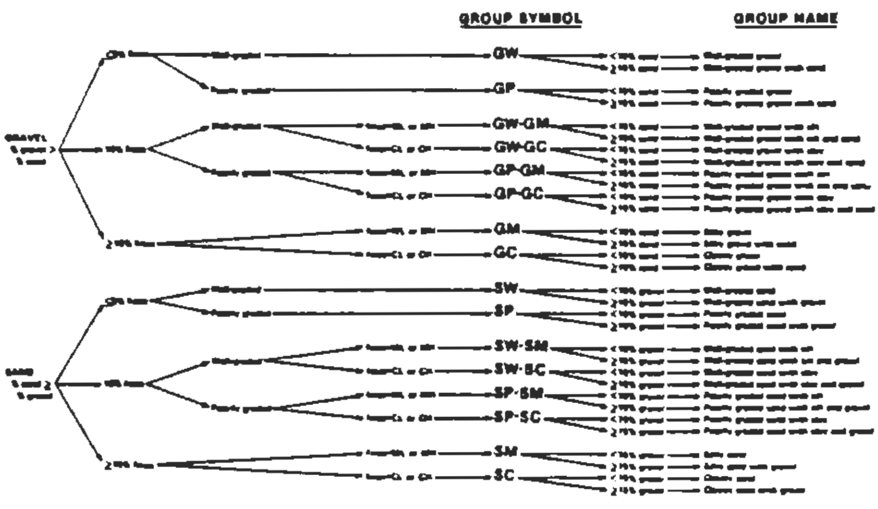
Sheet wash: Overland flow of water not concentrated in channels, generally in response to periods of heavy rainfall.


DECADE OF NORTH AMERICAN GEOLOGY
1983 GEOLOGIC TIME SCALE
DNAG
GEOLOGICAL SOCIETY OF AMERICA
CENOZOIC
MESOZOIC
PALEOZOIC
PRECAMBRIAN
AGE (Ma)
MAGNETIC POLARITY
PERIOD
EPOCH
AGE
PICKS (Ma)
ERA
EON
BDY AGES (Ma)
QUATERNARY
PLEISTOCENE
CALABRIAN
PLIOCENE
PIACENZIAN
ZANCLEAN
MESSINIAN
TORTONIAN
SERRAVALLIAN
LANGHIAN
BURDIGALIAN
AQUITANIAN
CHATTIAN
RUPELIAN
PRIABONIAN
BARTONIAN
LUTETIAN
YPRESIAN
THANETIAN
UNNAMED
DANIAN
SELANDIAN
NEOGENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
PALEOGENE
TERTIARY
CRETACEOUS
MAASTRICHTIAN
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANGINIAN
BERRIASIAN
NEOCOMIAN
JURASSIC
TITHONIAN
KIMMERIDGIAN
OXFORDIAN
CALLOVIAN
BATHONIAN
BAJOCIAN
AALENIAN
TOARCIAN
PLIENSBACHIAN
SINEMURIAN
HETTANGIAN
TRIASSIC
NORIAN
CARNIAN
LADINIAN
ANISIAN
SCYTHIAN
LATE
MIDDLE
EARLY
PERMIAN
TATARIAN
KAZANIAN
UFIMIAN
KUNGURIAN
ARTINSKIAN
SAKMARIAN
ASSELIAN
CARBONIFEROUS
PENNSYLVANIAN
MISSISSIPPIAN
GZELIAN
KASIMOVIAN
MOSCOVIAN
BASHKIRIAN
SERPUKHOVIAN
VISEAN
TOURNAISIAN
DEVONIAN
FAMMENIAN
FRASNIAN
GIVETIAN
EIFELIAN
EMSIAN
SIEGENIAN
GEDINNIAN
SILURIAN
PRIDOLIAN
LUDLOVIAN
WENLOCKIAN
LLANDOVERIAN
ORDOVICIAN
ASHGILLIAN
CARADOCIAN
LLANDEILAN
LLANVIRNIAN
ARENIGIAN
TREMADOCIAN
CAMBRIAN
TREMPEALEAUAN
FRANCONIAN
DRESBACHIAN
PROTEROZOIC
ARCHEAN

Appendix 3

Unified Soil Classification Systems





MODIFIED MERCALLI INTENSITY SCALE OF 1931
(Abridged)

I. Not felt except by a very few under especially favorable circumstances.

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls made cracking sound. Sensation like heavy truck striking building; standing motor cars rocked noticeably.

V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken, a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.

VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures, considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbed persons driving motor cars.

IX. Damage considerable in specially designed structures; well designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.

XI. Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

Source: Earthquake Information Bulletin, 6 (5), 1974, p. 28